



Lockheed
Engineering & Sciences Company

SPACE STATION EVOLUTION

NASA/JSC - CREW AND THERMAL

BY: ERIC OLSSON

DATE: FEB/90

SPACE STATION FREEDOM CENTRAL THERMAL CONTROL SYSTEM EVOLUTION

Richard Bullock

Crew and Thermal Systems Division

NASA - Johnson Space Center

Eric Olsson

Lockheed Engineering and Science Company

Houston, Texas

For Presentation at the Space Station Evolution Symposium

South Shore Harbour, League City, Texas

February 6-8, 1990

OBJECTIVE

The objective of the evolution study is to review the proposed growth scenarios for Space Station Freedom and identify the major CTCs hardware scars and software hooks required to facilitate planned growth and technology obsolescence.

The Station's two leading evolutionary configurations are: (1) the Research and Development node, where the fundamental mission is scientific research and commercial endeavors, and (2) the Transportation node, where the emphasis is on supporting Lunar and Mars human exploration. These two nodes evolve from the from the assembly complete configuration by the addition of manned modules, pocket labs, resource nodes, attached payloads, customer servicing facility, and an upper and lower keel and boom truss structure. In the case of the R & D node, the role of the dual keel will be to support external payloads for scientific research. In the case of the Transportation node, the keel will support the Lunar (LTV) and Mars (MTV) transportation vehicle service facilities in addition to external payloads. The transverse boom is extended outboard of the alpha gimbal to accommodate the new solar dynamic arrays for power generation, which will supplement the photovoltaic system.

The design, development, deployment, and operation of SSF will take place over a 30 year time period and new innovations and maturation in technologies can be expected. Evolutionary planning must include the obsolescence and insertion of the new technologies over the life of the program, and the technology growth issues must be addressed in parallel with the development of the baseline thermal control system. Technologies that mature and are available within the next 10 years are best suited for evolutionary consideration as the growth phase begins in the year 2000. To increase TCS capability to accommodate growth using baseline technology would require some penalty in mass, volume, EVA time, manifesting, and operational support. To be cost effective the capabilities of the heat acquisition, transport, and rejection subsystems must be increased.

OBJECTIVE

IDENTIFY PRINCIPAL HOOKS AND SCARS FOR SSF TCS GROWTH

- RESOURCE GROWTH - Physical Expansion
 - R & D Node: 300kW, +4 Modules, +4 Nodes, +3 Pocket Labs, CSF, Dual Keel
 - TRAN Node: 175kW, +2 Modules, +4 Nodes, +1 Pocket Lab, CSF, Dual Keel, LTV, MTV
- TECHNOLOGY GROWTH - Technology Upgrades
 - 30 Year Program Can Expect Technology Obsolescence
 - Continued Utilization of Baseline Technology Will Substantially Increase:
 - Radiator Area and Associated Sweep Volume
 - EVA Assembly Time
 - Orbiter Manifesting Penalties (Weight & Volume)
 - Orbital and Ground Operational, Maintenance, and Repair Support
 - Cost Effective Growth of the Evolutionary TCS Requires
 - Increased Capability in the Heat Acquisition, Transport, and Rejection Subsystems
 - More Autonomous Monitoring and Controls
 - Essential Analytical Tools Must Be Developed

AGENDA

The presentation begins with a review of the TCS requirements for growth. The principal hooks and scars are then identified followed by the provisions for growth and design issues for each subsystem. The major technology issues are discussed, and finally the conclusions are presented.

AGENDA

- REVIEW OF TCS GROWTH REQUIREMENTS
- IDENTIFY THE PRINCIPAL CTCs HOOKS AND SCARS AT ASSEMBLY COMPLETE
- DESCRIBE THE PROVISIONS AND PERTINENT DESIGN ISSUES FOR EACH SUBSYSTEM TO ACCOMMODATE GROWTH TO THE R & D NODE OR TRANSPORTATION NODE
- IDENTIFY MAJOR TECHNOLOGY GROWTH ISSUES AND REQUIREMENTS
- CONCLUSIONS

TCS REQUIREMENTS FOR GROWTH

As a result of the program rephrasing in late 1989, the most recent Space Station program documentation does not reference growth. Previous SSP documentation, such as the SSP 30000, JSC 31000, and SSP 30258, addressed growth issues of functionality, operation, TCS capacity, adding individual systems and elements, component modularity, and technology insertion. The JSC 31000 is a Johnson Space Center (WP2) document that reflects the higher level requirements specified in both the SSP 30000 and the TCS Architectural Control Document SSP 30258.

The most notable growth requirement is the fourfold increase in heat rejection for the R & D node at 325 kW, and for the transportation node it more than doubles at 200 kW. In general the requirements for growth are the same as for assembly complete. Modularity is very important to growth in that at the ORU level upgrades are technologically transparent and do not introduce integration problems. Modularity also supports the need for technology upgrades to be introduced without causing a major system interruption..



Lockheed
Engineering & Sciences Company

SPACE STATION EVOLUTION

NASA/JSC - CREW AND THERMAL

BY: ERIC OLSSON

DATE: FEB/90

TCS REQUIREMENTS FOR GROWTH

TCS REQUIREMENT

- * HEAT REJECTION CAPABILITY
- ON ORBIT RECONFIGURATION
- * MODULARITY
- SAFETY
- LEAK DETECTION
- QUIESCENT OPERATION
- REDUNDANCY
- ISOTHERMALITY
- MONITOR & CONTROL
- * TECHNOLOGY ACCOMMODATION

APPLICATION

75 kW (82.2 kW) --> 300 kW (325) or 175 kW (200)
VARIABLE TEMPERATURE LEVEL, HEAT LOAD
SPACE ERECTABLE, REPLACEABLE
95% MINIMUM OPERATIONAL CAPABILITY
5% PER YR (PER LOOP) MAX LEAKAGE
10% OF FULL LOAD
TWO FAULT TOLERANCE
 $\pm 2.0^{\circ}\text{C}$
MINIMUM CREW INVOLVEMENT
NO MAJOR SYSTEM INTERRUPTION

PRINCIPAL HOOKS AND SCARS

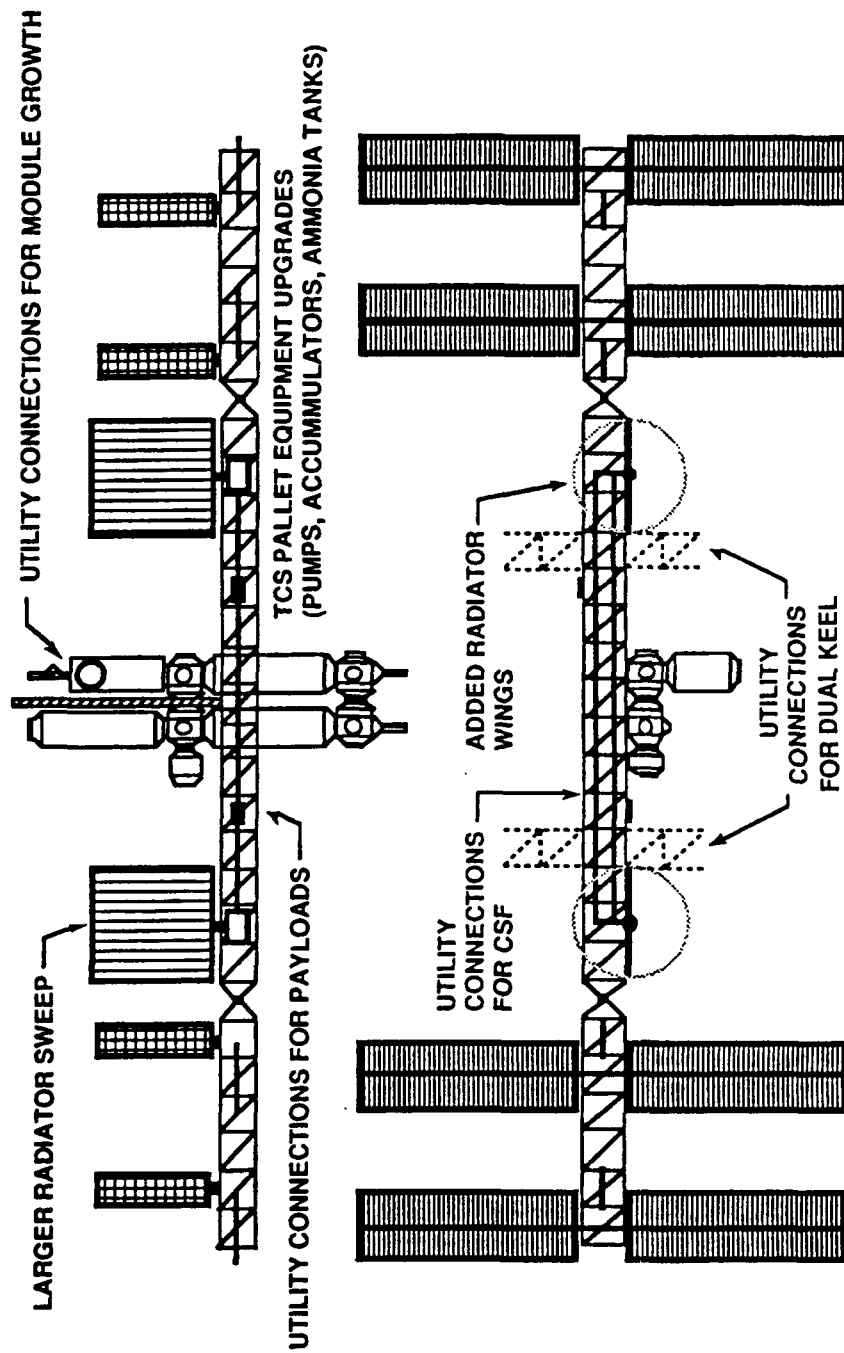
The principal scars to the CTCS to accommodate growth are similar for both the Research and Development node and the Transportation node. Growth elements include added modules; a dual keel with an upper/lower boom; a servicing facility; attached payloads and, in the case of the Transportation node, Lunar and Mars transportation vehicle servicing facilities.

The principal scars to the CTCS include:

- Utility connections for module growth, attached payloads, customer servicing facility, dual keel, LTV facility, and MTV facility.
- Larger thermal radiator wing sweep radius due to added radiator panels.
- Two added thermal radiator wings.
- Upgrading of TCS pallet equipment (pumps, accumulators, filters, etc.) to support the higher ammonia mass flow rates.
- Upgrading and expansion of the TCS monitoring and controls software and hardware to support the added TCS equipment.

PRINCIPAL HOOKS AND SCARS

PRINCIPAL HOOKS AND SCARS FOR R & D NODE AND
TRANSPORTATION NODE ARE SIMILAR



EXPANSION OF TCS MONITORING & CONTROLS SUBSYSTEM (SHARED SPD AND MDM'S)

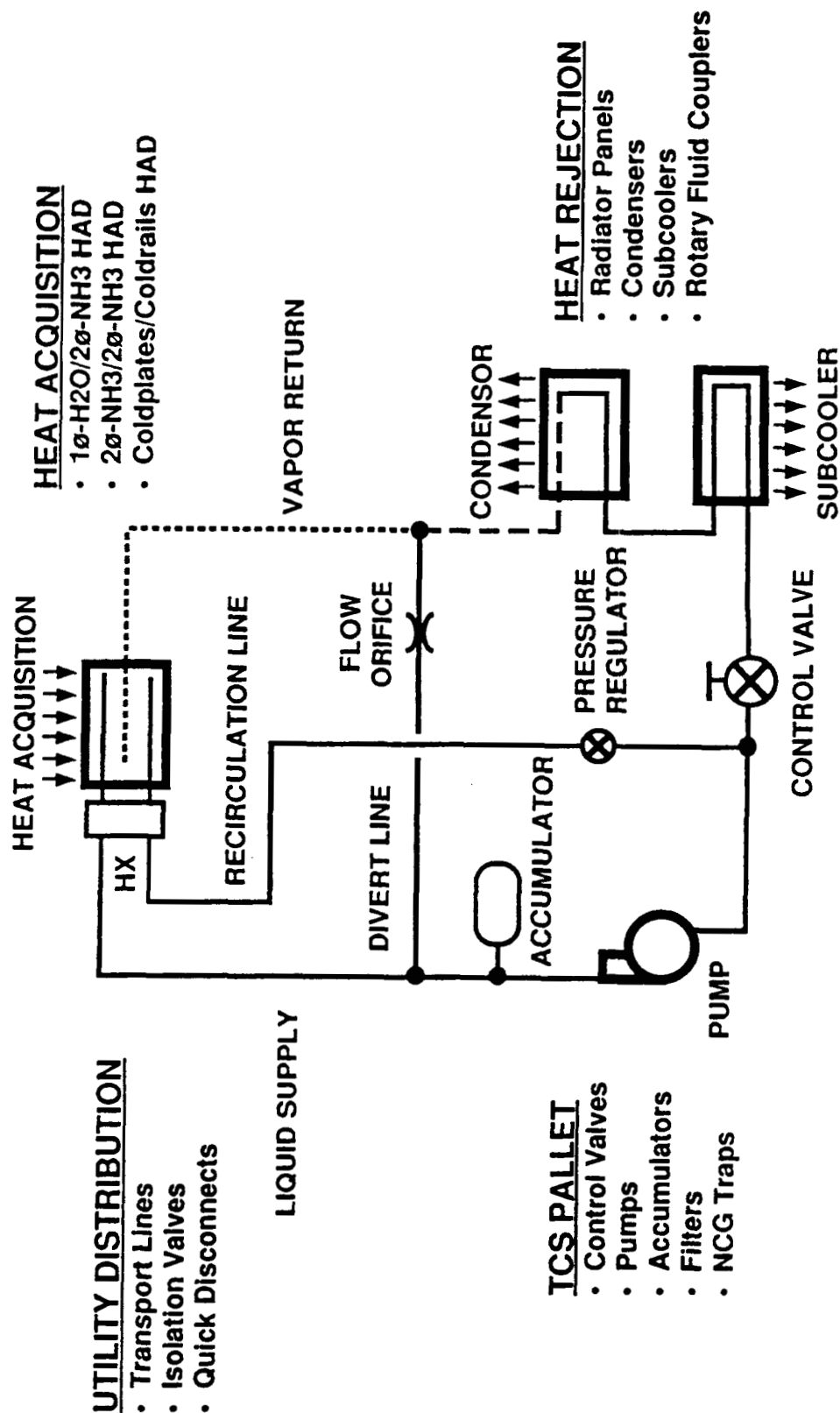
CTCS FLOW SCHEMATIC AND SUBSYSTEMS

The CTCS collects heat from heat sources and transports the heat to thermal condensers where it is rejected to space. It consists of two fully redundant ammonia loops (4 total), one operating at 2°C (35°F) and the other at 21°C (70°F). The moderate temperature loop (21°C) can be reconfigured to a low temperature loop if required. At assembly complete, the CTCS is designed for a maximum heat rejection of up to 82.2 kW, which is comprised of electrical (75 kW), metabolic (136.7 W/person), parasitic, and environmental thermal loads.

The heat acquisition devices (HAD's) collect heat from several different types of equipment, so several interface geometries are used. The HAD's absorb heat through an evaporation (latent heat) process which enables the bus to maintain a nearly constant temperature. The vapor is transported through the vapor lines to the condensers, and the unused liquid is returned to the pump after passing through a supply/return heat exchanger local to each HAD. The HAD's are mounted on the exterior endcones of the modules and nodes. The HAD's and condensers are interconnected by transport lines in utility trays which shield the liquid and vapor lines from damage caused by orbital debris. The pumping equipment and the thermal radiators are located at each end of the Transverse boom, inboard of the alpha gimbals. The pallet equipment includes pumps, filters, accumulators, and control valves. The heat rejection system consists of dual thermal radiator wings made of modular heat pipe radiator panels. The radiator wings are rotated about the X-axis to maintain a "cold" thermal environment during Earth-orbit. Radiator rotation is made possible through a rotary fluid coupler (RFC) mounted directly to the CTCS pallet. The RFC allows liquid and vapor to pass through the device yet enables continuous rotation through 360°.

The provisions for growth and design issues for the major CTCS subsystems: heat acquisition, heat transport, TCS pallet equipment, and heat rejection are discussed in the sections that follow.

CTCS FLOW SCHEMATIC AND SUBSYSTEMS



HEAT ACQUISITION GROWTH

Growth of the heat acquisition system is related directly to the number of new elements that are planned for growth. The Station elements and the corresponding number of heat exchangers for the assembly complete configuration increase from 40 at assembly complete to 141 for the R & D node and 101 for the Transportation node. For the purposes of assessing growth requirements it was assumed that the external payloads are actively cooled. The HAD total weight increases from 4660 lbs at assembly complete to 15570 lbs for the R & D node and 10890 lbs for the Transportation node.

To understand the impact on the CTCS of adding (capillary) HAD's, it is necessary to explain the operational characteristics of the HAD. HAD operation is dependent on specific line pressures in the supply, return, and vapor tubes. The pump supply pressure is throttled and mass flow rate is regulated by an orifice at the inlet of each HAD. The minimum flow rate depends on the HAD thermal capacity, but is approximately 150% of that required for the design heat load. The liquid first passes through a supply-return heat exchanger to raise its temperature from a subcooled state. This process also provides cooling to the low quality return liquid. The maximum HAD pressure occurs in the vapor line and is set by the saturation pressure corresponding to the bus operating temperature. The minimum pressure is in the return line and must exceed the bubble point pressure of the wick to prevent HAD dryout, which is about 10 psid below the vapor pressure. The HAD supply pressure, downstream of the orifice, is less than the vapor pressure but greater than the return line pressure. Some consequences of violating these pressure limits are (1) HAD flooding if the supply line pressure exceeds the vapor pressure; and (2) the HAD will become inoperable if the supply pressure falls below the wick bubble point pressure causing a loss of suction in the return line.

A pump, oversized during the growth phase, will impose a higher system supply pressure than initially required, but is necessary to support the longer supply line lengths and the new flow requirement that accompanies expansion. The complication arises with the flow redistribution. The flow control orifices, local to each HAD, must be adjusted individually as the system changes. Each adjustment depends, in part, on the particular HAD location and design heat load, and must also satisfy the pressure limits stated above. For growth, the orifices should be variable sizing and adjustable from remote locations by the TCS control system. Instrumentation will also be required at each HAD to measure flow rate and line pressures to assist in making the adjustments.



Lockheed
Engineering & Sciences Company

SPACE STATION EVOLUTION

NASA/JSC - CREW AND THERMAL

BY: ERIC OLSSON

DATE: FEB/90

HEAT ACQUISITION GROWTH

RESOURCE	AC		R & D		TRANS	
	UNITS	HX/CP	UNITS	HX/CP	UNITS	HX/CP
MODULES	2 US, 2 I	12	6 US, 2 I	28	4 US, 2 I	20
RESOURCE NODES	4	8	8	16	8	16
POCKET LABS	-	-	3	6	1	2
ATTACHED PAYLOADS	-	-	18	36	8	16
CSF	-	-	1	3	1	3
LTV + MTV FACILITY	-	-	-	-	1	4
DDCU COLDPLATES	20	20	52	52	40	40
TOTAL HX	40		141		101	
TOTAL WEIGHT (LBS)	4660		15570		10890	

PROVISIONS FOR GROWTH

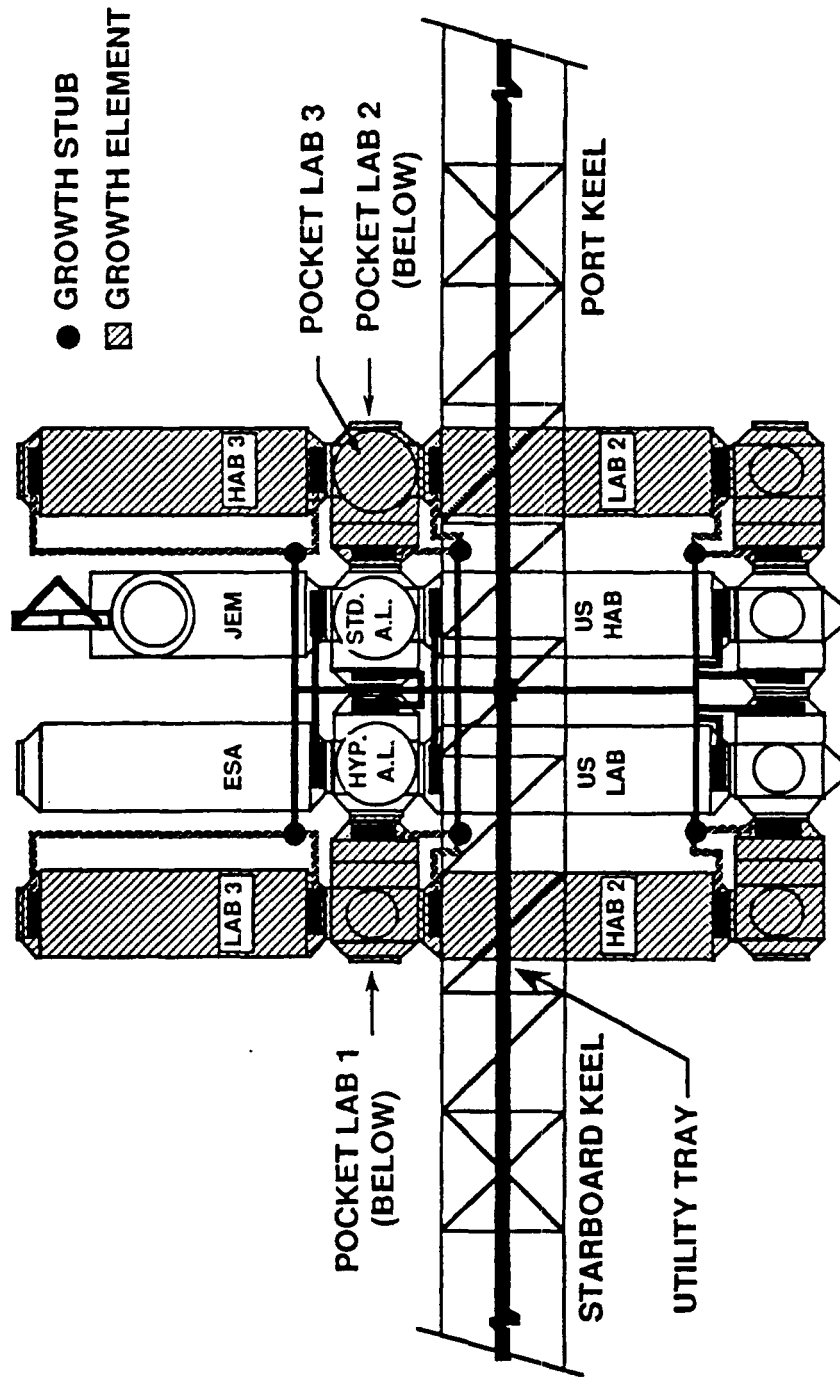
- VARIABLE FLOW ORIFICES WILL BE REQUIRED FOR CAPILLARY HEAD'S TO ACCOMMODATE ADJUSTMENTS IN SYSTEM PRESSURE AND FLOW RATES ASSOCIATED WITH PHASED GROWTH
- GROWTH STUBS ARE REQUIRED ON THE SECONDARY (OR UMBILICAL) CTC'S BRANCH FEEDS OFF THE TRANSVERSE BOOM FOR EXPANSION OF THE MODULES AND NODES

R & D MODULE CTCS FLUID DISTRIBUTION

A preliminary layout of the fluid distribution system for the R & D and node is shown, and is similar for the Transportation node. A characteristic of module growth for both nodes is that it occurs in the $\pm Y$ direction (along the transverse boom) - not in the $\pm Z$ direction. The $\pm X$ direction has always been preserved for orbiter docking maneuvers. Growth stubs will be required in the secondary (or umbilical) CTCS branch feeds to accommodate the expansion of the transport lines for the added modules, resource nodes, and pocket labs. These are required in both the primary and redundant distribution lines and consist of isolation valves and quick disconnects.

R & D MODULE ATCS FLUID DISTRIBUTION (PRELIMINARY)

MODULE GROWTH IS IN THE $\pm Y$ DIRECTION. GROWTH STUBS ARE TO BE PROVIDED ON THE SECONDARY ATCS FLUID DISTRIBUTION BRANCH.



UTILITY DISTRIBUTION GROWTH

Ammonia distribution is baselined as part of a dedicated fluid utility system, meaning it is independent of EPS and DMS distribution lines. Two fluid trays run parallel with the transverse boom, one positioned in the upper and the other in the lower quadrant of the truss assembly. In each tray, the TCS transport lines consist of two liquid supply lines, two recirculation lines, two vapor lines, plus two liquid and two vapor crossover lines. The transport lines are not ORU's in the strictest sense, therefore, for growth, it is essential that the transport lines be sized for the mass flow rate corresponding to the highest expected heat rejection requirement over the life of the Station. The valves and quick disconnects must be sized accordingly. The transport lines should be sized at 325 kW for the R & D node and 200 kW for the Transportation node. For growth, the total line length increases from 7000 feet at assembly complete to approximately 13600 feet (2.6 miles). The weight of the transport lines (without ammonia), valves, and quick disconnects increases from 1610 lbs to approximately 10500 lbs.

Utility ports to accommodate future connections to the CTCS transport lines are necessary. The MDSSC "pop-up" utility port is essential for this growth provision and is installed as a link in the utility tray during Station assembly. The dual keel will extend in the $\pm Z$ direction and will require utility ports at PB4 and SB5. It is important that the heat rejection requirements on the upper and lower keel/boom be defined to allow proper sizing of the valve connections as a growth scar. The keels involve long line lengths and pressure drop will be a governing factor. The customer servicing facility will require a utility connection at SB3 (upper).

TCS growth requirements for other distributed systems are also being identified for growth planning. These include (1) Communications and Tracking, (2) Guidance, Navigation, and Control, (3) Extravehicular Activity Systems, (4) Data Management System, and (5) Propulsion. The results of these studies are not yet available.

From a growth perspective, the passive heat rejection requirement for attached payloads should be supplemented with a provision for active cooling. Passive heat rejection techniques require specific viewing orientations and could experience degraded performance as the Station changes, such as with the addition of the dual keel and other growth elements. The scar to the Station for including this provision is minimal and consists of a "pop-up" utility port.



UTILITY DISTRIBUTION SYSTEM GROWTH

ITEM	AC	R&D	TRAN.
LINE LENGTH (FT)	7000	13415	13605
VALVES/QD'S	390	1005	895
TOTAL WEIGHT (LBM)	1610	11170	9660

PROVISIONS FOR GROWTH

- LINES, VALVES, AND QD'S NEED TO BE SIZED FOR GROWTH
- DEPLOYABLE "POP-UP" UTILITY PORTS REQUIRED FOR DUAL KEEL (PB4, SB5) AND CUSTOMER SERVICE FACILITY (SB3)

DESIGN ISSUES

- TCS GROWTH REQUIREMENTS FOR DMS, GN&C, C&T, AND EVA HAVE YET TO BE SPECIFIED
- PTCS IS BASELINED FOR ATTACHED PAYLOADS AND PALLETS. PASSIVE HEAT REJECTION HAS RESTRICTED VIEWING REQUIREMENTS WHICH MAY BE DIFFICULT TO PRESERVE WITH GROWTH. CTCS UTILITY PORTS WILL BE REQUIRED IF ACTIVE COOLING IS REQUIRED IN THE FUTURE
- THERMAL REQUIREMENTS FOR DUAL KEEL ARE NEEDED FOR TCS GROWTH PLANNING

TCS PALLET GROWTH

The heat transport system consists of pumping equipment located on two TCS pallets and transport lines which are routed throughout the Station. The pumping equipment is essentially identical for each of the four thermal loops and includes: (1) for active components - pumps, accumulators, control valves; and, (2) for passive components - dual filter systems, noncondensable gas traps (NCG), and flow orifices. This equipment is located on the starboard pallet at SB7 and the on port pallet at PB6. Four supply and dump tanks are located on each pallet, but are common to all four loops. The thermal radiator wing and pallet equipment are interconnected through the rotary fluid coupler mounted to each pallet. Crossover lines interconnect the thermal radiator wings with each thermal loop, although only the radiator wing at the pallet where the loop pumping equipment is located is utilized under normal operation. The thermal radiator wing on the opposite pallet is available for redundancy. The HAD thermal load is equally divided, at each temperature, between the primary and redundant systems.

Growth requirements for the CTCS pallet equipment are not major since the quantity of equipment remains the same - only the size changes. The pumps (8), accumulators (2), filters (8), and noncondensable gas traps (4) are ORU's and will require upgrading to higher capacity units to accommodate larger ammonia mass flow rates. The most significant impact to pallet growth is the reserved volume allocation and fluid connections for the new forward rotary fluid couplers mounted on each pallet. The dual radiator wing are deployed in the fore (+X) and aft (-X) directions.

The Station ammonia inventory will increase with the addition of the new heat exchangers, transport tubing, and dual keel. The inventory is a function of the volume in the liquid and vapor lines where the addition of the dual keel has a large affect. The total ammonia inventory increases by approximately 41% - from 1860 lbm to 2625 lbm. The ammonia inventory at assembly complete will be insufficient and will require greater allocation for growth.

TCS PALLET GROWTH

QUANTITY DOESN'T CHANGE - ONLY SIZE

PROVISIONS FOR GROWTH

- FLUID HANDLING (ORU) EQUIPMENT IS INITIALLY SIZED FOR KW. UPGRADING EQUIPMENT TO LARGER CAPACITY EQUIPMENT MAY REQUIRE INCREASED VOLUME ALLOCATION
 - PUMPS (8)
 - ACCUMULATORS (2)
 - FILTERS (8)
 - NCG TRAPS (4)
- LARGER FILL AND DRAIN TANKS TO ACCOMMODATE ADDED AMMONIA INVENTORY WITH ADDITION OF DUAL KEEL (INCREASES FROM 1600 LBM TO 3200 LBM)
- VOLUME ALLOCATION FOR ADDED FORWARD ROTARY FLUID COUPLERS REQUIRED ON EACH PALLET
- TCS FLUID CONNECTIONS REQUIRED IN EACH LOOP FOR ADDED ROTARY FLUID COUPLERS

HEAT REJECTION GROWTH

The heat rejection system is made-up of modular units consisting of heat pipe radiator panels, condenser modules, subcooler modules, and a supporting truss assembly. Each radiator wing is configured into four heat rejection sections to support the primary and redundant 35°F and 70°F thermal loops. The ammonia vapor enters a condensing unit, is liquified, and then routed to a subcooler unit to be further cooled below the saturation point before returning to the pump. The condenser and subcooler units accommodate up to six panels and four panels, respectively. They are modular and can be increased with phased growth, and are physically secured by a modular transition beam and truss assembly. The radiator panels are modular and space erectable, due in part to a dry contact and pressurized interface with the condensing unit. This interface is advantageous because the radiator panels are easily installed and amenable to growth. At assembly complete, the total thermal load is divided equally between two radiator wings, and for growth is distributed over four wings.

The load fraction between the two loop temperatures is very important for growth planning. The load fractions, for baseline, are 36% on the 35°F loop, and 64% on the 70°F loop; however these are subject to change. They are impacted by customer loads and subsystem loads, which are still being defined. The radiator heat rejection is proportional to the fourth power of temperature and, therefore, the total number of panels is affected by the percentage of load at each temperature. Using standard design conditions the (net) orbital average heat rejection rates for the 35°F and 70°F thermal buses are approximately 960 W and 1500 W respectively. For the baseline load fractions the number of radiator panels increase from 82 at assembly complete, to 296 for the R & D node, and 188 for the Transportation node.

The heat rejection subsystem constitutes the largest percentage of the total weight of the CTCS. It is 65% of the total weight at 12075 lbs for assembly complete. For growth to the R & D node the weight increases to 39835 lbs and for the Transportation node it increases to 26400 lbs.

HEAT REJECTION GROWTH

ITEM	AC	R & D *	TRAN *
RADIATOR WINGS	2	4	4
HEAT REJECTION SYSTEM			
Radiator Panels	74	280	172
Condenser Modules	14	48	32
SUBCOOLING SYSTEM			
Radiator Panels	8	16	16
Subcooling Modules	4	4	4
SWEEP RADIUS (FT) **	26	46	29
TOTAL WEIGHT (LBM)	12075	39835	26400

* ASSUMES 5% SAFETY FACTOR, AND 36% @ 2°C AND 64% @ 21°C

** ASSUMES 3 INCH PANEL SPACING

PROVISIONS FOR GROWTH

- CONDENSERS ARE MODULAR AT FIXED (6 PANEL) EXPANSION INCREMENTS
- CTB CONDENSER SUPPORT STRUCTURE MUST BE MODULAR
- SWEEP VOLUME FOR THERMAL RADIATOR WINGS BOTH FORE AND AFT OF TCS PALLETS MUST BE PRESERVED

HEAT REJECTION (CON'T)

In the case of the R & D node, the radiator wing sweep radius is affected by the available clearance between the EPS thermal radiator and the 6.9 foot corridor required for EVA. The nearest EPS thermal radiators are positioned one bay outboard of the alpha gimbal at PA1 and SA1. The clearance between the thermal radiator wing and the EPS radiator does not accommodate the EVA corridor and, in fact, could result in physical interference depending on which radiator spacing is used. At a radiator spacing greater than 1.75 inch, physical contact will result. Preliminary testing at Johnson Space Center has shown that 1 inch spacing can be achieved for assembly and maintenance; however, even at 1 inch, the EVA corridor is limited to 2.6 feet. No physical interference or EVA clearance problems were found to exist for growth to the Transportation node.



Lockheed
Engineering & Sciences Company

SPACE STATION EVOLUTION

NASA/JSC - CREW AND THERMAL

BY: ERIC OLSSON

DATE: FEB/90

HEAT REJECTION GROWTH ... Con't

DESIGN ISSUES

- PANEL-TO-PANEL RADIATOR SPACING AFFECTS RADIATOR TOTAL SWEEP DIMENSION. FOR R & D NODE, WITH 1 INCH PANEL SPACING ONLY 2.6 FT CLEARANCE IS AVAILABLE BETWEEN CTCS AND EPS THERMAL RADIATORS. THE REQUIRED EVA CLEARANCE IS 7 FT.
- HEAT LOAD SPLIT BETWEEN 2°C AND 21°C THERMAL LOOPS AFFECTS TOTAL NUMBER OF PANELS (36% LOAD ON 2°C BUS, 64% LOAD ON 21°C BUS). THIS LOAD FRACTION IS SUBJECT TO CHANGE.
- PRESENCE OF CSF REDUCES RADIATOR HEAT REJECTION BY 1% ($\beta=0$) to 5% ($\beta=52$).

TCS MONITORING AND CONTROL HIERARCHY

The TCS monitoring and control subsystem consists of a three tier hierarchy. Tier I is the highest level, and involves general directives issued from the crew (or ground) and provides information concerning the health and status of a particular subsystem, such as the TCS. At Tier II, the TCS shares a standard data processor (SDP) with other subsystems and communicates with Tier I through a run time object data bases (RODB). Detailed software procedures to operate, identify faults, and initiate corrective action resides at Tier II. Tier III, unlike Tier I or Tier II, is external to the manned modules and involves hardware dominated equipment rather than software. It is at Tier III where the interface with the external ORU's occurs, via sensors and effectors, and the most significant impact to growth is realized. MDM's are used for data acquisition and provide the interface with the SDP by way of the shared local bus.



Lockheed
Engineering & Sciences Company

SPACE STATION EVOLUTION

NASA/JSC - CREW AND THERMAL

BY: ERIC OLSSON

DATE: FEB/90

TCS MONITORING AND CONTROL HIERARCHY

TIER I - STATION OPERATION

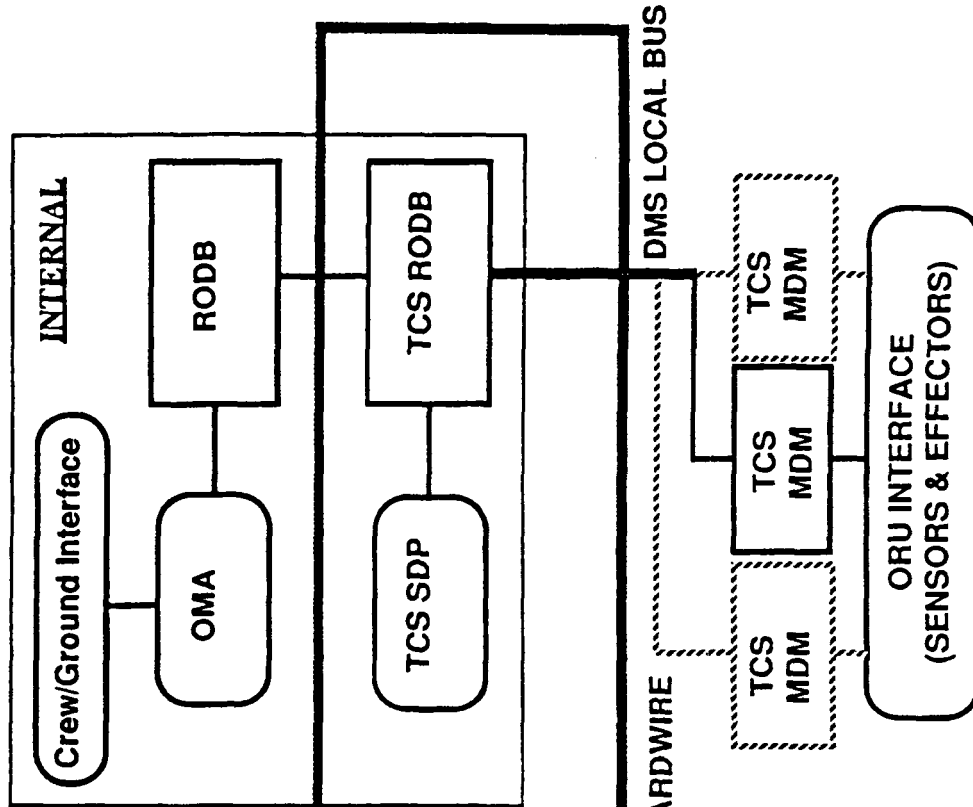
- Subsystem Directives, Health, and Status

TIER II - SUBSYSTEM OPERATION

- TCS Software Procedures
- Component Status and Performance Data
- Fault Detection, Identification, and Recovery (FDIR)
- External Local Bus Interface

TIER III - ORU OPERATION

- Data Acquisition and Signal Conditioning
- External Hardware Interface



MONITORING AND CONTROL GROWTH

Physical growth of the monitoring and control system is proportional to the quantity of ORU's and distribution lines added to support the physical expansion of the Station. Each Tier of the monitoring and control subsystem is impacted by growth: Tier I involves software hooks; Tier II involves hooks and possibly scars if the local bus capacity is an issue; and, at Tier III the impacts are primarily hardware oriented. Identification of scars at the Tier III level is essential for growth since it is external to the pressurized modules and volume must be reserved for hardware and connections.

At assembly complete, the total number of signals for TCS monitoring and controls is approximately 4,200, and increases to 12,000 for the R & D node and to 10,000 for the Transportation node. The signals are made-up of instrument and valve status indications (open/close and condition), commands, and instrument readings. Instrument redundancy is also included. The total number of sensors increase from 675 at assembly complete to 1050 for the growth configurations. Additional signals translate directly into more MDM's. The TCS baseline makes use of "mini"-MDM's which have 64 available ports as compared to 256 ports for standard MDM's. Each MDM is hardwired to the DMS local bus and requires an access port near its location. MDM's are generally shared with other distributed systems, but considering the number of added signals for TCS alone, it can be conservatively estimated that at least 120 additional mini-MDM's will be required. An alternative is that the mini-MDM's be replaced with standard MDM's which have excess capacity at assembly complete. At Tier II, software upgrades are expected due expanded Station resources and TCS expanded FDIR capability. Tier I will also require software upgrades to reflect the changes in Tier II.



MONITORING & CONTROL GROWTH

PROVISIONS FOR GROWTH

- TIER III - EXTERNAL SCARS
 - ADDED SENSORS (T, P, Δ P, Q) INCREASE FROM 675 TO 1050. EXPERT SYSTEM TECHNOLOGY WILL INCREASE THIS FURTHER.
 - VOLUME ALLOCATION FOR MDM'S. TOTAL NUMBER OF SIGNALS INCREASE FROM 4200 TO 12000. THIS TRANSLATES TO 120 ADDED MINI-MDM'S (64 PORTS EA).
 - LOCAL BUS INTERFACE PORTS FOR ADDED MDM'S
- TIER II - INTERNAL HOOKS
 - (SDP) SOFTWARE UPGRADES
 - (RODB) INCREASED MEMORY ALLOCATION
- TIER I - INTERNAL HOOKS
 - SOFTWARE ENHANCEMENTS

DESIGN ISSUES

- BASELINE DOES NOT FULLY SUPPORT AUTOMATED FAULT RECOVERY
- SUBSTANTIAL INCREASE IN SYSTEM COMPLEXITY WITH GROWTH OF HARDWARE COMPONENTS

TECHNOLOGY GROWTH

Technology issues may be organized into specific areas of focus: academic, component, and system issues. Academic issues refer to state-of-the-art models, methods, and techniques. Component issues pertain to individual hardware items that could emerge as a result of advances in discipline issues and increased operational experience. The distinction between component and system issues is that changes at the component, or ORU, level are by nature technologically transparent, where system level changes are not and may involve integration problems.

Several academic issues play a role in the technical development of thermal equipment for space applications. A fundamental issue includes the need for mechanistic models for two-phase flow in microgravity environments. Without complete confidence in the analytical tools, the designer is forced to impose greater conservatism into the design, which will increase component mass and cost. Another issue of fundamental interest is the long-term stability of surface properties of coating materials. Space applications of thermo-optical coating include thermal radiators, multi-layer insulations, antennas, booms/structure, and PV solar arrays to name a few. A fundamental understanding of the degradation in the mechanical and thermo-optical properties due to atomic oxygen depletion, solar radiation (UV), ionizing radiation, and micrometeoroids and debris needs to be established.

At the ORU level, improvements to component performance, weight, volume, safety, and reliability, can be implemented through component replacement; therefore, scars are not required. Internal issues still remain, such as whether or not new pressure or temperature levels are called for and if these affect the performance of other equipment. Improvements are expected at the component level as discipline issues are resolved and operational experience with ORU's grow.

System level improvements signify improvements involving a basic departure from baseline hardware components and include some form of integration question. Besides the overall benefit of the technology insertion, integration issues are the drivers for hooks or scars. Hooks and scars are very challenging this context because the integration problems are to be resolved before the actual components are invented. A primary candidate for a system level improvement includes a higher capacity heat pipe radiator that may require a new condenser design to match its capability. This may in-turn involve a new truss structure for physical support. Several concepts relevant to the thermal control system can be discussed such as heat pump cycles, to raise the system operating temperature, and thermal bus condensers that eliminate the dry contact thermal resistance. A significant technological advancement will be the introduction of AI technology into the monitoring and control system.

TECHNOLOGY GROWTH

■ ACADEMIC ISSUES

- ESTABLISH FUNDAMENTAL UNDERSTANDING OF MICROGRAVITY TWO-PHASE FLOW TECHNOLOGY WITH ASSOCIATED ANALYTIC DESIGN AND SIMULATION TOOLS
- LIFE OF THERMO-OPTICAL COATING MATERIALS DUE TO DEGRADATION WITH ATOMIC OXYGEN DEPLETION, SOLAR AND IONIZING RADIATION, AND METEROID/DEBRIS

■ COMPONENT LEVEL ISSUES - ORU REPLACEMENT

- MINIMIZE INCREASE OF RADIATOR AREA (~65% CTCs WEIGHT, VOLUME) WITH HIGHER HEAT FLUX RADIATOR PANELS
- ACHIEVE BETTER CONTACT CONDUCTANCE BETWEEN THERMAL BUS AND RADIATORS
- INCREASE HEAT FLUX CAPABILITY OF H₂O/NH₃ HEAT EXCHANGER

■ SYSTEM LEVEL ISSUES - INTEGRATION ISSUES

- ADVANCED HEAT PIPES - ARTERIAL FLOW, COMPOSITES, ETC
- HEAT PUMP CYCLE - HIGHER TEMPERATURE FOR HEAT REJECTION PURPOSES
- CONDENSERS - INTEGRAL CONCEPTS
- INSTRUMENTATION - TWO-PHASE VOID FRACTION, LEAK DETECTION
- MONITORING AND CONTROLS - EXPERT SYSTEMS
- THERMAL STORAGE (CAPACITANCE)

CONCLUSIONS

The hook and scar assessment for evolution of Space Station Freedom to the Research and Development node and Transportation node is complete for this phase of evolution definition. In general, the baseline CTCs equipment is designed with modularity as a priority and can accommodate new components resulting from technology enhancements.

Fundamental to the hooks and scars for growth are that the CTCs transport lines, valves, and quick disconnects are sized for the maximum growth power allocation.

For resource growth, the principal hardware scars are grouped into one of two categories: (1) fluid connections for modules, external payloads, servicing facilities, and the rotary fluid coupler, and (2) volume allocation for larger thermal radiators and added MDM's. Dedicated SDP's and software hooks may accompany the added sensors for data acquisition. Clearance between the CTCs thermal radiators and EPS thermal radiators is an issue for growth to the R & D node. It is recommended that an option for active cooling of the attached payloads be provided.

For technology growth, the hooks and scars are not so clearly defined. The most significant hardware contribution will come from enhanced radiator concepts that offer both greater heat rejection and reduced weight. The motivation is the continued use of the baseline heat rejection technology the radiator mass and volume will become significant, if it is not already. A fundamental understanding of two-phase flow in microgravity along with the analytical simulation and design tools will assist in achieving this goal. Introducing AI technology into the TCS monitoring and controls system is highly desirable and will necessitate the need for added sensors, MDM's, and dedicated processor requirements. This will serve to minimize EVA and reduce orbital and ground operational support. However, since it is still early in the development of expert system technology, these needs are not clearly understood.

CONCLUSIONS

- SIZE TRANSPORT LINES, VALVES, QD'S FOR GROWTH POWER ALLOCATION.
- PRINCIPAL SCARS TO CTC'S INCLUDES:
 - FLUID CONNECTIONS FOR MODULES, PAYLOADS, DUAL KEEL, SERVICING FACILITIES, AND RFC.
 - VOLUME ALLOCATION FOR THERMAL RADIATORS AND MDM'S.
- FOR GROWTH TO THE R & D NODE, CLEARANCE BETWEEN CTC'S AND EPS THERMAL RADIATORS IS A POTENTIAL PROBLEM. FOR THE TRANSPORTATION NODE, PHYSICAL AND EVA CLEARANCE IS PROVIDED.
- THE CTC'S COMPONENT THAT HAS THE BIGGEST IMPACT ON GROWTH IS THE THERMAL RADIATOR; BOTH IN VOLUME ALLOCATION AND WEIGHT.
- DEPENDENCE ON ONLY PASSIVE COOLING OF TRUSS MOUNTED EQUIPMENT (APAE'S, PALLETS) WILL NOT BE ADEQUATE FOR GROWTH. BLOCKAGE EFFECTS DUE TO GROWTH SHOULD BE INCLUDED AND UTILITY PORTS FOR FUTURE CONNECTION TO THE CTC'S SHOULD BE PROVIDED.
- MONITORING AND CONTROLS SHOULD BE MORE AUTOMATED USING AI TECHNOLOGY. SOFTWARE AND AUTOMATION APPLICATION DEVELOPMENT IS STILL AT "INFANCY STAGE" WHICH INSTILLS A LEVEL OF UNCERTAINTY WITH REGARD TO GROWTH REQUIREMENTS.
- FULLY VERIFIED THEORETICAL MODELS AND DESIGN ALGORITHMS DO NOT EXIST FOR MICROGRAVITY TWO-PHASE PROCESSES, RESULTING IN OVERLY CONSERVATIVE DESIGN HARDWARE.
- A STRONG EMPHASIS HAS BEEN PLACED ON MODULARITY IN BASELINE REQUIREMENTS WHICH PROVIDES A LEVEL OF FLEXIBILITY TO ACCOMMODATE GROWTH.